ON THE

# STEAM-GENERATING POWER

OF

# MARINE AND LOCOMOTIVE BOILERS.

BY

CHARLES WYE WILLIAMS, ESQ.

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I.—ON THE ASSUMED VALUE OF TUBE SURFACE.

II.—ILLUSTRATIONS OF THE VALUE OF FACE-PLATE SURFACE.

III.—LAW FOR REGULATING THE AREA OF FACE-PLATE SURFACE.

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BY

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# ON MARINE AND LOCOMOTIVE BOILERS.

## I.—ON THE ASSUMED VALUE OF TUBE SURFACE.

It will doubtless, hereafter, be a matter of special wonder, when the construction of boilers shall have been perfected, to find that for thirty-four years, since Stephenson's *Rocket* won the prize for the locomotive, we have been following an *ignis fatuus*—the so-called heating surface of tubes; and that so far from that surface being the measure of the heat-transmitting and evaporative power, it may, in fact, be altogether omitted in our calculations, and for the measure of that power, we shall have to look to a different portion of the boiler—a portion hitherto absolutely unnoticed and unappreciated by engineers. The experiments and proofs, hereafter detailed, fully establish this fact beyond question.

In my Paper on the Construction of Marine Boilers, read in March, 1862, at the meeting of the Institution of Naval Architects, I drew attention to the important distinction between the *generation* and the *application* of heat—that is to say, 1st, the realizing the greatest amount of heat in the *furnace;* and, secondly, the application of that heat in the *boiler*, in promoting the greatest amount of evaporation. To these points and the relative values of the several surfaces which the boiler presents, the following remarks will be directed.

Of the tube internal surface, as regards its heat-transmitting and steam-generating property, we may, as will hereafter be shown, on the authority of the late Mr. Dewrance and Mr. Hick of Bolton, estimate its efficiency, in comparison with that of the furnace or firebox plates, at but one-tenth of the gross nominal surface it presents, where the tubes are not more than six feet long. My own numerous experiments and observations fully bear out this statement.

Again, when the tubes are ten feet long or upwards, we will not err much, if, with the exception of the first *twelve inches*, we leave them altogether out of our calculation, and regard them as mere conduits for conveying the heated products of combustion to the chimney.

This exception of twelve inches will be understood when we consider that the ends of the tubes being exposed to the full heat of the furnace must be very hot, if not almost

red hot, (particularly where iron ferrules are used), and consequently that the tubes, for some distance, would thus become steam generators.

Against the insufficiency of the tubes as heat transmitters and steam generators we have the hitherto neglected surface of the *face-plate*—presenting a face to the direct action of the hot currents from the furnace. Assuming that the orifices of the tubes occupy one-fourth of the gross area of the face-plate, the practical heat-transmitting portion will be the remaining three-fourths.

In general terms, then, we may say that whatever may be the gross area of the face-plate in marine boilers, three-fourths, certainly not less than two-thirds of it, at the least, should be capable of receiving the direct action of the heated current from the furnace.

The main difficulty under which engineers labour consists in providing, not *nominal*, but *effective* heat-transmitting surface, apart from that of the crown and side plates of the furnace.

This difficulty was early felt by George Stephenson in his first locomotive, the *Rocket*. His son, the late Robert Stephenson, observed "Other engines were made, all "having in view the increase of the heating surface, as it became obvious to my father "that the speed of the engine could not be increased without increasing the evaporative "power of the boiler." The inference was strictly correct; his error (hitherto unexamined) lay in the assumption that the evaporative power would be increased by an increase in the length of the tubes.

Had he been aware of the superior value of the face-plate surface as a steam generator, he would have increased the area or number of those plates, rather than the length of the tubes. Instead of increasing that length to 13 feet, as he did, had he divided the space into three compartments, each containing tubes of 3 feet long, with intervening spaces for the heated currents to collect and strike each succeeding face-plate as they did the first, he would have greatly increased the steam-generating power of the boiler, and thus have supplied the desideratum which he failed to obtain, and which still remains to be effected by his successors.

Hitherto, the face-plate has been regarded as a mere mechanical contrivance by which the tubes were held in their places for preserving certain distances between them to enable the water to surround them. Strange to say, no idea whatever appears to have been entertained that the face-plates had any heat-transmitting or steam-generative property *of their own*.

As perforated diaphragms, however, which they practically are, their true function

and merit consists in their suddenly intercepting the current of hot gaseous products from the furnace, and appropriating a portion of the heat of that current to the generation of steam in the water immediately behind, and in contact with them. The amount of heat transmitted to the water through them will then be the measure of the steam-generative value of these plates.

The now proposed system, as I have elsewhere stated, consists in substituting for the ordinary long tubes employed, sets or series of short tubes or flues at short distances apart, the ends of each set or series being fitted into tube or face-plates like those into which the long tubes are united.

That no heat-transmitting power was attributed to the face-plates is manifest from the fact, that while Brunel was careful to estimate the so-called heating-surface power of the *Great Eastern's* boilers at so many tens of thousands of square feet of tube-surface, not a single foot was set down to the numerous face plates in connection with the large number of 112 furnaces*—a number considerably beyond what would have been required had the generated heat been properly directed. In fact, the heat-transmitting value of the 112 face-plates was altogether ignored—yet these were the real steam generators which supplied his enormous engines.

Now this supposed absence of heat-transmitting power can no longer prevail, as the violent ebullition which cannot be mistaken, and which we see continuously produced immediately behind the face-plates, at once disproves the inference that they had no evaporative property of their own. So far, indeed, is this ebullition in excess of what could have been expected, that it is only by personal inspection of a tube boiler, as seen when open, and before the top is laid on, that any adequate idea can be formed of the extraordinary heat-transmitting property of these face-plates, and the volume of steam thereby generated.

There is a fact which, although hitherto unobserved, here merits special notice, as it exhibits a remarkable contrast between the action of the gaseous current passing *through* the tubes in the one case, and *against* the face-plate in the other, namely, that in proportion as the chimney draught is *increased*, so is the heat-transmitting power of the face-plate surface, whereas that of the tube surface is *diminished*.

* The published statement of the engineers gives the following particulars of the *Great Eastern's* boilers, *viz.*: "Every "paddle boiler has ten furnaces, and each screw boiler twelve furnaces, thus giving to the whole the large number of one "hundred and twelve furnaces. These paddle boilers are in two distinct sets, and each set has about 8,000 square feet of "tube surface, exclusive of flue and furnace, and about 400 square feet of fire-bar furnace."

Of the seven engines, it says, "The boilers are of the same kind as the paddle boilers, only six in number and each "boiler has twelve furnaces, while those of the paddle engines have only ten. The seven engines, will be supplied with "steam by six boilers, each boiler having twelve furnaces. Each set of boilers has a surface of 9,000 square feet, say, "1,600 brass tubes, 3 inches in diameter outside and 5 feet 6 inches long."

This will readily be understood, when we consider that in the tubes the heated current passes, with extraordinary rapidity, *along the plane of their internal surface;* whereas, in the face-plate, it strikes with *a direct force* at right angles to that surface. The same may be said of flue boilers, and which are often made of no less than 30 feet in length. In these the current of heated products passes along the plane of their interior surface, manifestly, as in the case of tubes, giving out but little heat, *laterally*, to the course of that current.

We here at once recognise the cause of the great steam-generative power of the *single face-plate* in each locomotive, namely, the almost electric rapidity of the draught in the chimney, producing a corresponding increase in the force with which the heated current strikes that plate.

Although the use of the tubes in Stephenson's first locomotive took place in 1830, it was not until they were introduced into marine boilers that I began to have any doubts as to their merits. This doubt became a certainty, on finding that in one of the most efficient boilers in a vessel of the Dublin Steam Company the tubes were but 3 feet long.

Aware of some experiments having been made by Mr. Dewrance, then the chief engineer of the Liverpool and Manchester line, I applied to him in 1858 for his experience as to the steam-generative value of the tube system. In reply to my inquiry, he said:—"In reply to your inquiries as to the experiments made by myself and Mr. "Woods, about the year 1842, as to the evaporative effect of the *tube* portion of a "locomotive boiler, I have to say that we had one of the boilers employed on the "Liverpool and Manchester line divided, so as to separate the water in the *tubular* portion "of the boiler from that in connection with the firebox portion. In a subsequent "experiment I divided a small boiler into six different compartments, so that I could "ascertain the weight of water evaporated in each. The first compartment was but "6 inches long, the remaining five were each 12 inches, the tubes being 6 feet 6 inches "long. The result was, that each square foot of the heat-absorbing surface in the first "compartment was about equal to a square foot of the firebox surface. In the second "compartment, each square foot of tubular surface was estimated at about one-third of "that value; but in the remaining four compartments the evaporation was so small as "to raise a doubt on my mind whether it had any value at all. In fact, I came to the "conclusion that the first 6 inches of the tubular series had more evaporative effect "than the remaining 60 inches." Here was ample encouragement for further inquiry, the heat-transmitting property of the tubular surface being so seriously impugned. A similar experiment had been made by the late Mr. Benjamin Hick, of Bolton, a competent and able experimenter. The conclusion that he came to was, that each 10 feet of tube surface had only the heat-transmitting power of 1 foot of furnace

surface. My own experience goes far in corroboration of these data, as will presently be seen.

Looking at the extraordinary inefficiency of the tube surface which he discovered, he may well be justified in inferring:—"That the evaporation of the last 4 feet of the "tubes was so small as to raise a doubt in his mind whether they had any value at all; "the first 6 inches of the tubular series doing more than the remaining 60 inches."

The effect produced by the direction in which the heated current strikes the surface may aptly be compared to the rolling of a cannon ball rapidly along a sheet of ice, as compared with the letting it fall vertically on its surface. The simile is perfect; for in proportion as the rapidity of the motion of the ball along the plane of the ice is increased, so will its effect be *diminished;* whereas, as the rapidity with which it falls is *increased*, so also are its effects.

In the prevailing use of the tubular system, we have a proof of the slow progress which improvement makes when unaided by experiment. The error into which Stephenson fell, in believing that the quantity of steam generated would be increased in a commensurate degree by an increase in the length of the tubes, prevails to this day, as we shall presently find on reference to the British and Foreign locomotives.

When the tubular system was adopted, it was accompanied (and for the first time,) with the passing of the waste steam from the cylinder into the chimney. The result was considered so conclusive as to leave no room for doubt. The steam chimney blast or jet, and the draught it occasioned, secured adequate combustion of fuel and generation of heat in the furnace, while the tubes were *assumed* to supply its appropriation, and give the necessary generation of steam. Had, however, the two principles been tested separately, (which was never done,) it would have been found that nearly the whole of the favourable result was really due to the action on the face-plate by the powerful draught which the steam blast produced, and the commensurate increase of force with which the gaseous current struck that plate.

The *Rocket* had but twenty-five tubes, 6 feet long, presenting the insignificant aggregate of $117\frac{3}{4}$ square feet. The area of the whole face-plate was about 400 square inches, and that of the tube orifices about 100; thus leaving 300 square inches (the working portion of the face-plate,) available for intercepting the hot gaseous current from the firebox. Here then was the true surface, which not only won the prize of £500 for Stephenson, but laid the foundation of all the subsequent wonders of the locomotive; yet the value of that surface remains to this day unrecognized and unappreciated.

The superiority of the combination was stated to consist "in the rapidity of the

"combustion in the firebox keeping pace with the rapidity of motion of the Locomotive "itself, on which depended the draught *through the tubes*, and consequently" (a most erroneous and mischievous inference) "the amount of steam generated from the water "exposed to the large extent of heated surface they presented." Here we have in this oversight the source of all our subsequent errors, and which unfortunately prevails to this day.

To exemplify these facts I had a boiler constructed on the plan adopted by Mr. Dewrance, so that the heat-transmitting value of each lineal foot of the tube would be indicated. The tube was 5 feet long, divided into 6 compartments. The first compartment was confined to a single inch of the tube; the second to 10 inches, and the remaining four, each to 12 inches. The extreme violence of the ebullition in the first compartment of but 1 *inch* of the tube was so great, as to require an enlargement of the space above it. The following, after three hours work, was the result:—

| First Compartment of but 1 inch evaporated. | Second of 10 inches. | Third of 12 inches. | Fourth of 12 inches. | Fifth of 12 inches. | Sixth of 12 inches. |
|---|---|---|---|---|---|
| lb. oz. | lb. oz. | lb. oz. | lb. oz. | lb. oz. | lb. oz. |
| 2 14 | 2 15 | 1 14 | 1 6 | 1 2 | 1 1 |

Here we see the first compartment, of but a *single inch*—(virtually the face-plate)—evaporated nearly as much as the next 10 inches; while these first 11 inches did more than the remaining 48 inches. Here we have an unquestionable confirmation of Mr. Dewrance's remarks, as to the valueless character of the last 4 feet of the tube.

Encouraged by this result, I had a boiler made of the size of that of the *Rocket*, with 25 tubes of 6 feet long, the result was equally satisfactory.

Mr. D. K. Clark, in his able Analysis of the Locomotives collected at the Intertional Exhibition of 1862, has given us the means of examining the peculiarities of each, and has also added his own views of their practical value. I propose here giving some interesting extracts from that Analysis, which has not only its own merits, but now comes opportunely in furnishing a valuable corroboration of the principles I am here endeavouring to enforce.

In the English locomotives he shews that the length of the tubes has been reduced to 9 feet 4 inches (still more than three times the length which will hereafter be found most beneficial). In Foreign engines, however, the length has been increased, and even beyond what Stephenson tried and found ineffective.

Generally speaking Mr. Clark condemns, and justly so, the limited clearance or space between the tubes. On this he observes, in reference to an engine by Bayer and

Peacock, which he considers characterized by "thoroughness, and finish in form and "detail, and is a type of the prevalent state of English inside cylinder express engines." He adds:—"The boiler, in consequence of the great width of the Portuguese guage, "(5 feet $4\frac{3}{4}$ inches) has a large square firebox, 4 feet 10 inches in each way; nevertheless, "for effective heating surface, a firebox of oblong form, would, in the writer's opinion, "be better. There are 215 tubes of 2 inches diameter, placed at ·56 inches apart; had "the tubes been only $1\frac{7}{8}$ diameter, which, upon the whole, the writer considers the best "size, and placed in the same position, the larger clearance of ·69 so obtained of "circulation, would have improved the evaporative efficiency."

Thus he not only recommends the enlargement of the clearance space between the tubes, but the reduction of the tubes themselves, from 2 inches to $1\frac{7}{8}$; yet, it is remarkable that he here omits to notice that both these changes would have the direct result of enlarging the effective heat-intercepting surface of the face-plates. Thus, unconsciously, he would promote the true source of increased evaporation.

The enlargement of the clearance space from ·56 to ·69 would be so insignificant as to have no perceptible effect on the circulation of the water; but, combined with the enlargement of the heat-receiving area, by the diminution of the diameter of the tube, it would have a remarkable effect on the heat-receiving surface, and the amount of heat transmitted.

The mere reduction in the size of the tubes, in this case, would, in fact, give the important addition of 81 square inches to the heat-transmitting area of the face-plate, as thus:—

| | | Square inches. |
|---|---|---|
| 215 Tubes, 2 inches diameter ... ... ... | Area = | 675·444 |
| " $1\frac{7}{8}$ " ... ... ... ... | " | 593·651 |
| Gain of effective heating surface ... ... | | 81·793 |

The opportunities for observation by Mr. Clark on so many British and Foreign locomotives, compels him to recognize the over-estimate of the tube surface. In speaking of one of the engines of the London and N.W. Railway, he says:—"The grate is 7 feet "long, in two parallel stripes, and the enormous amount of 242 square feet of heating "surface has thus been attained in the firebox and combustion chamber. This great "extension has led to the curtailment of the tubes to 9 feet 4 inches in length, and it has "been attempted to compensate for this, by packing 214 tubes together, at ·50 in distance "apart—making 940 square feet of heating surface in the tubes." Of this over-estimate of the value of the tube surface Mr. Clark adds:—"The opinion has been extensively held "that heating surface is mechanically the equivalent of evaporating power; but this has "not been confirmed by experience."

He next describes an engine by Sharp, Stewart and Company, for the Dover Railway, which merits special notice from the great disproportion between the grate surface and that of the tubes:—" The firebox measures 7 feet 3 inches long, and has 27½ square feet " of grate, with 189 tubes of 2 inches diameter, with ·67 inches clearance, and within a " 4-feet 2-inch barrel." On this, Mr. Clark observes, " that 160 tubes, with ·75 inches " clearance would have been better." Still *omitting to notice the increased heat-receiving area of the face-plate.*

He next describes an engine by Armstrong and Company, with 5 feet 6 inches guage, for the Indian Railway, the tubes being 10 feet 11 inches long, 2¼ diameter, with clearance ·56. On this, he remarks:—" These proportions might be improved by reducing " the tubes to 2 inches diameter, with increased clearance, and the reduction of this " heating surface would be amply compensated by the increased facility for circulation " of the water and steam between the tubes." Here again he recommends the diminution of the tubes' diameter, and the enlargement of the clearance, on the sole ground of deficient circulation of the water, but without contemplating or appearing to have any idea of the value of the increased area of the face-plate effective surface, which would be the result.

Of the Foreign locomotives he describes the *Dromedaire*, built for the Northern Railway in France. This engine has 28 square feet of grate, and the total heating surface of 1667 square feet, having 356 tubes of $1\frac{9}{16}$ inch diameter, with but ·44-inch clear spaces between the 356 tubes. On this he justly observes—" There can be no " doubt that *half the number* of tubes, properly placed, would have answered the purpose " decidedly better" (still overlooking the face-plate surface). In this department of the Foreign engines we see the great error of long tubes carried to excess. On the Orleans Railway the tubes are not less than 14 feet 5 inches long, while in the Austrian State they are even 14 feet 6 inches long, as shewn in the following table:—

| Railway. | Fuel used. | No. of Tubes. | Length of Tubes. | Clear Space between Tubes. | Total Heating Surface. |
|---|---|---|---|---|---|
| | | | Feet. In. | | Feet. |
| Orleans ........................ | Coke | 187 | 14 5 | — | 1,263 |
| North of France ............ | Slack | 356 | 11 5 | ·44 | 1,558 |
| Belgian ........................ | Slack | 225 | 11 6 | ·62 | 1,192 |
| Austria, heavy tank ......... | Coke | 158 | 14 6 | ·69 | 1,245 |
| Austria, passenger ......... | Coke | 160 | 14 6 | ·62 | 1,260 |
| Windsor and Coln ......... | Coke | 156 | 13 9 | — | 960 |

These details are specially valuable in shewing the prevailing error of estimating the steam-generative power as correlative with the gross area of the tube surface, and also of the absolute neglect of that of the face-plate.

In truth, its very existence as a heat-transferring medium seems to be absolutely ignored. That this oversight still continues to prevail is manifest from the opening address of Mr. Fairbairn, as President of the British Association. In that he says—"I well remember the competition at Rainhill, in 1830. Neither George Stephenson "himself nor any one else had the most distant idea of the capabilities of the railway "system. The sagacity of George Stephenson at once seized the suggestion of Henry "Booth to employ tubular boilers, and that, united to the blast pipe, has been the means "of effecting all the wonders we now witness." From this it is clear in the opinion of Mr. Fairbairn and his contemporaries, that the combination of the tubular system and the steam jet has been the means of producing the perfection of boiler arrangement; a result, which, as far as tube surface is concerned, I have shown to be altogether erroneous.

The discovery of the tubular system, and the steam blast, by which its efficiency was produced, has several claimants; none, however, have discovered the true source of that efficiency—namely, the heat-transmitting property of the face-plate, and its vertical position being so favourable to the function of intercepting the heated gaseous current from the firebox.

Mr. Zerah Colburn, in his work on locomotive engines,* has gone at length into the disputed question as to the priority of the discovery, yet has himself passed wide of the mark, advocating the value of the tube surface without perceiving its relative insufficiency; and of the steam blast, without reference to the *modus operandi* on which that value depended.

He takes pains to ascertain whether this so-called "invention" was due to Stephenson or Booth, Neville or Sequin.

Where, however, is the value of this labour and investigation, as to priority of invention, when we find that in the absence of any enquiry, or even reference to the true source of its evaporative effect, this "invention," has not only been without any results that could lead, practically, to improvement, but has been the source of great mischief by perpetuating error, and giving it a fictitious value which has since led practical men still further astray in their enquiry after truth?

Mr. Colburn's work is not only well got up in every respect, but will hereafter be a valuable text-book for locomotive engineers—containing much important information and a series of admirably executed plates.

Had any of the competitors, however, discovered the true ground on which the

* *Locomotive Engineering and the Mechanics of Railways*, by Zerah Colburn, Esq., Civil Engineer.

tubular system was based, as to its merits, and so that those merits might have become available, they would have done the engineering world some service, and the priority of the invention would have been worthy of a contest. What has been done has been not only a barren discovery, as to principle, but has led the world, during 30 years, from one false step to another, until we see its climax in a system of tubes carried to the extent of 14 feet 6 inches, under the erroneous conception of a merit to which it has no claim. Had they made the true discovery, on which the tube system depends for value, not only would there have been a great increase of speed gained, but an incalculable saving of fuel, now uselessly expended in producing the great mischief of enormously heated products escaping by the chimneys.

In his work, Mr. Colburn speaks of a "generator in which the heated products of "combustion are *split into numerous streams* by tube flues." The supposed value of this splitting of the heated products of combustion into numerous streams, is based on a serious mistake in supposing that those small attenuated streams had the faculty of giving out heat laterally to the course of those streams. Now, it is well known that rays of heat or light do not radiate laterally to their course, and that their effect depends on their striking in a vertical direction, or as near to that as possible. As well might we suppose that the rays of the setting sun, as they pass beside us on the line of the earth's surface, and giving out their lengthened shadows on the ground, were equally powerful as those which strike downwards with vertical force at noon; or, that a cannon ball glancing along the side of an iron-clad steam ship, and in the line of its iron plates, would have equally destructive force with one striking in a point blank direction, and vertical to these plates.

The insufficiency of the tubular surface was clearly demonstrated at the Newcastle experiments, where an addition of 40 tubes, with a surface of 320 square feet, intended to take up the waste heat in the chimneys, (an addition of nearly three times that of the 117 square feet the entire tube-surface of the *Rocket*), could only extract 45° out of the 600°, the temperature of the escaping waste heat in the chimney.*

In truth, the prevailing opinion and practice comes to this, that, where larger engines are required, and greater steam power is to be supplied, engineers have no alternative but that of enlarging the furnaces and increasing their number to a mischievous and wasteful

* "The heater which was used for the purpose of heating the feed water slightly increased the co-operative effect, by "its additional absorbing surface. This increase was, however, much less than might have been expected from the large "absorbing surface of the heater, which contained 320 square feet; yet it was found that when the products of combustion "before entering the heater were at 600 degrees, the passage through it did not reduce the temperature more than 40 to "50 degrees."—*Report of Messrs. Armstrong, Richardson, and Longridge.*

extent, together with an addition to the length and number of the tubes, under the erroneous impression that a corresponding increase of evaporation would be the result. Both of these changes, however, are alike destructive of economy and efficiency.

Had they only examined (as should always be done) the action of the several parts of the boiler,—its several organs, so to speak,—when each could be seen and its merits appreciated, the perpetuation of the great mistakes we are daily committing would have been avoided, and the true heating surface discovered. Yet this neglect in examining the action of the several parts or organs of the boiler is not less culpable than if surgeons were to ignore dissection, or the examination of the functions of each organ of the body, and trust to observation of the exterior human frame.

In a word, the *insufficiency* of the tubes, as steam generators, has been practically their real *protection.* Had they transmitted heat sufficient to generate any quantity of steam, they would soon have been destroyed, as no water could then possibly have found its way between them, and where nothing but steam from below would have existed.

How lamentably erroneous, then, has been the whole system of tubular boilers, and the reference to the tube surface as the measure of the evaporative power of a boiler. The sooner that this fallacy is exposed the better, otherwise we must go on floundering in a mischievous and expensive course of error.

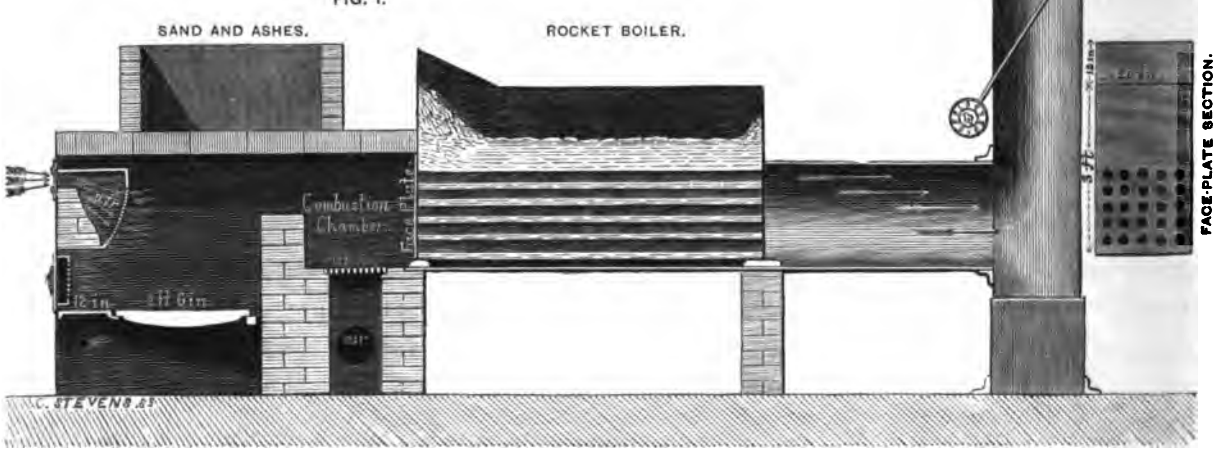
Mr. Colburn, in the preface to his work on the locomotive engine, speaks of the "commercial importance of the utmost excellence in that admirable machine." In promoting that excellence he has done all that an author or an engineer could do. He could only describe the machine and its excellence as he found it, and as it exists at the present day. It is therefore no disparagement to his work that the locomotive is still comparatively imperfect, and is susceptible of great improvement. The preceding details prove, that as regards what may properly be called its most important feature—the means by which the heat is transmitted to the water, and steam generated—the machine is, up to the present moment, most lamentably deficient. I now proceed to give practical illustrations on the large scale of the evaporative value of the face-plates.

## II.—ILLUSTRATIONS OF THE VALUE OF THE FACE-PLATE SYSTEM.

For the purpose of testing the practical value of the face-plate system, on a working scale, I adopted it in a boiler, which I will call the *Rocket* boiler, being of the same size and arranged like that of Stephenson, having twenty-five tubes, 6 feet long $2\frac{1}{4}$ inches diameter.

The first experiment made with it was to ascertain the full evaporative value of the *tubes*, apart from that of the furnace or firebox. In a furnace 30 inches by 18 inches wide, 420 lbs. of coal were used in three hours, and 1,970 lbs. of water evaporated from 212°. The temperature of the escaping products in the chimney, as indicated by Gauntlett's pyrometer, was 1,060°, the water evaporated by each pound of coal being 4·69 lbs. The annexed Fig. No. 1 will show the nature and proportions of this boiler.

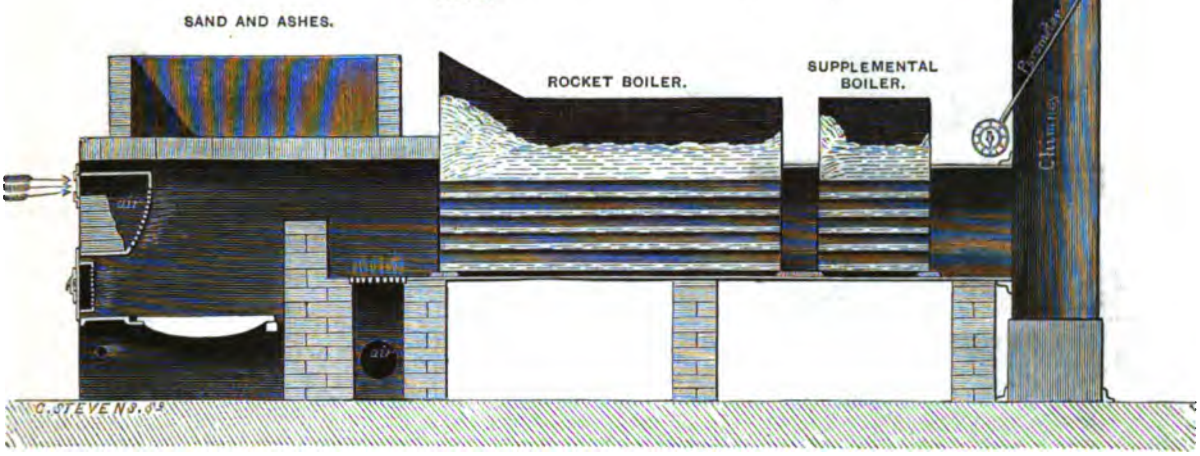
FIG. 1.




From the high temperature in the chimney (106,0°), it was evident that much of the heat that should have been appropriated in generating steam had passed away as *waste*. Here, then, was a favourable opportunity for ascertaining if any of that heat could be utilized.

For this purpose a small supplemental boiler was annexed, similar in every respect to the larger one, with the exception of having tubes of but 2 feet long instead of 6 feet. This reduction in the length of the tubes was made for the purpose of obviously throwing on its face-plate the work of evaporation. Between the two boilers was left an interval of 18 inches, as a heatbox, to allow the heated currents to collect and strike the second face-plate, as it did in the first instance (see Fig. 2).

FIG. 2.




The result of this arrangement, and the presence of a *second* face-plate was, that although the force of the draught was reduced by reason of the loss of the appropriated heat, and but 364 lbs. of coal used (against 420 lbs. in the previous experiment), the evaporation was *increased* from 1,970 lbs. to 2,080 lbs. as follows:—

| | |
|---|---|
| From the 6-feet tube boiler ... .. ... ... ... | 1,820 lbs. |
| From the 2-feet tube boiler ... ... ... ... | 260 „ |
| | 2,080 „ |

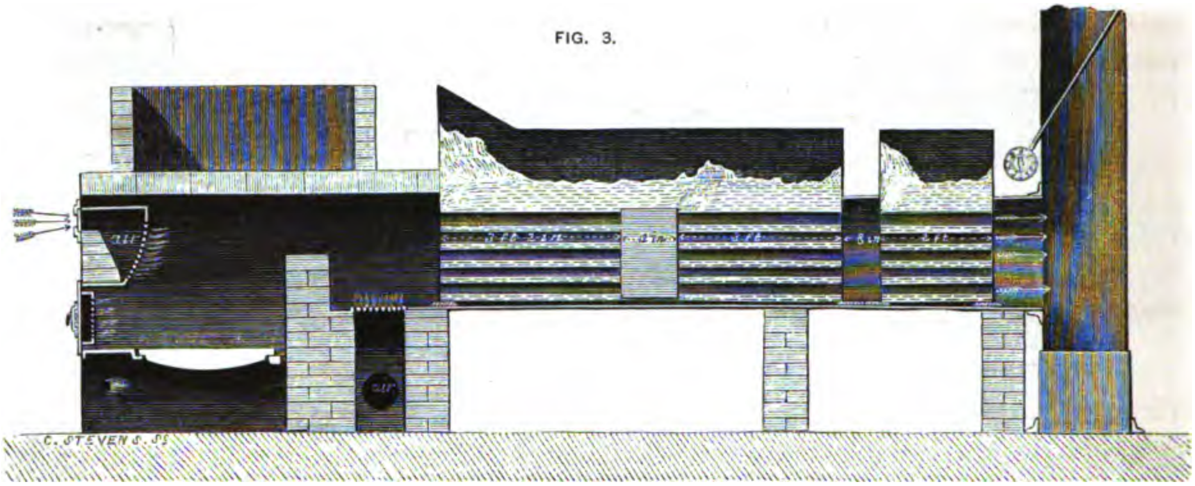
Here there was a gain of 110 lbs., or 5 per cent. more water evaporated, with a reduction of 56 lbs. in the coal used, or 14 per cent. The equivalent of this was shown in the reduction of the temperature in the chimney from 1,060° to 760°, and the evaporative value of each pound of coal increased from 4·69 to 5·69 lbs.

Now, the strong ebullition which continuously rose behind the face-plate of the supplemental boiler showed that it was there the increased evaporative effect was produced.

The third experiment was intended to test the heat-transmitting power of a *third* face-plate, in the expectation of utilizing still more of the escaping heat.

For this purpose, in place of the 6-feet tube boiler, with its one face-plate, a boiler was made having *two face-plates*, as if the 6-feet tubes had been divided into two portions, each having tubes of but 3 feet long, with an intermediate space of 18 inches, to act as a heat chamber, thereby allowing the heated products, from the first series of twenty-five tubes, to unite and strike the second face-plate as before. To this was annexed (as in the preceding experiment) the supplemental small boiler, thus giving the effect of a *third* face-plate, as shown in Fig. No. 3, next page.

FIG. 3.




The result was proportionately satisfactory. The combustion of 392 lbs. of coal produced a still further evaporation, as follows:—

| | |
|---|---|
| From the two-face-plate boiler, evaporated ... ... ... | 2,200 lbs. |
| From the small supplemental boiler ... ... ... ... | 240 „ |
| | 2,440 „ |

Still more of the escaping heat was utilized: the temperature in the chimney being further reduced from 760° to 635°, and the evaporative value of each pound of coal increased from 5·69 to 6·22 lbs. Here there was a practical illustration of the value, not only of *one* but of *two* face-plates, in addition to the original one belonging to all tubular boilers. Yet, the value of the face-plate, as a heat transmitter and evaporator has hitherto remained unappreciated and even unnoticed.

From the following tabular view of the results of the three experiments, all on the full working scale, we see that the difference between the evaporative power of the

| Description of Boiler. | Size of Furnace. | Weight of Coal used. | Difference. | Water evaporated. | Difference. | Heat in Chimney. | Evaporation per lb. of Coal. |
|---|---|---|---|---|---|---|---|
| | Inches. | lbs. | | lbs. | | Degrees. | |
| Stephenson's boiler, 25 tubes. | 30 by 18 | 420 | — | 1,970 | — | 1,060 | 4·69 |
| The same, with supplemental boiler and face-plate. | Ditto. | 364 | Less by 56 lbs. or 14 per cent. | Large boiler, 1,820<br>Small ditto . 760<br>2,080 | Gain of 110 lbs. or 5 per cent. | 760 | 5·69 |
| Double face-plate boiler, with supplemental boiler. | Ditto. | 392 | More by 28 lbs. | Large boiler, 2,200<br>Small ditto . 246<br>2,440 | Gain of 360 lbs. | 635 | 6·22 |

ordinary tube boiler, with its one face-plate, as in the first experiment, and that of the last, with its two additional face-plates, was an increased evaporation of 470 lbs. or twenty-four per cent. with even a saving of fuel.

It is easy to calculate the great value of such increased generation of steam in boilers of large size.

The following experiment is, perhaps, the most convincing illustration of the heat-transmitting power of the face-plate, and sets the question at rest.

The boilers here used were the same as were used in the last experiment, with this difference in their relative position: the supplemental boiler with its single face-plate being placed *in front*, and the large one behind it. The result is remarkable: the small 2-feet boiler, with its single face-plate, on receiving the full force of the heated current, actually evaporated more than the larger one, thus—

| Coals used. | Water evaporated. | | |
|---|---|---|---|
| 392 lbs. | Small boiler | ... | 1,250 lbs. |
| | Large boiler | ... | 1,070 „ |
| | | | 2,320 „ |

Here we have exhibited the extraordinary heat-transmitting power of the *face-plate*, as against the *tube surface power*, seeing that the face-plate when placed nearest the source of heat, evinced a commensurate steam-generative power.

In illustration of the importance of giving a sufficient clearance between the tubes, and its effect on the available area of the face-plates, I give the proportions in two cases of an ordinary boiler of the size of those in the *Warrior*. In both cases the number of tubes are taken at 100, in each stack, and of 3 inches inside diameter.

In the first case the clearance or space between the tubes is taken at 1 inch, and in the second 1¼ inch, between the tubes, *viz*:—

| | Square inches. | | Square feet. |
|---|---|---|---|
| Gross area of face-plate with 100 tubes and clearance of 1 inch | 2093·04 | | |
| Area of 100 tube orifices for draught to be deducted | 706·84 | | |
| Available area of surface | 1386·20 | = | 9·7 |

Second calculation:

| | | | Square feet. |
|---|---|---|---|
| Gross area of face-plate with 100 tubes and clearance of 1¼ inch | 2376·56 | | |
| Area of 100 tube orifices for draught | 706·84 | | |
| Available area of surface | 1669·72 | = | 11·7 |

Assuming the grate surface to be 18 square feet, say 6 by 3 feet, we have in the first case, but 9.7 square feet to receive and transmit the heat from 18 square feet of grate surface—about *one-half* the required quantity.

In the second case we have 11.7 feet of available heat-receiving area, being an increase of 2 square feet for each stack of tubes of perhaps 50 furnaces; such an increase on the whole must have a powerful effect in increasing the amount of steam generated. These latter proportions are found practically effective in some of the vessels of the Dublin Steam Company.

We thus see how erroneous has been the principle on which the heat-transmitting surface has been hitherto calculated, since the tubular system has been adopted, and that we have now to enter on an entirely different calculation in determining the proportions between the steam-generative properties of a boiler, and the horse-power for which steam has to be provided.

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## III.—LAW FOR REGULATING THE APPLICATION OF THE FACE-PLATE SURFACE.

From what has been said and the results here recorded, it will be seen that important changes will hereafter be made in the construction of boilers, for the purpose of bringing the hitherto-neglected surface of the face-plate more directly into action, and reducing the amount of heat escaping by the chimney.

The first will be a reduction in the length of the furnaces and firebox, and, consequently, of the weight of coal consumed; as it is manifest that no more heat need be generated than can be applied in the generation of steam, with the exception of that which is required for draught.

*Secondly:* An adequate length of run, or combustion chamber, will be provided in marine boilers, as it is in locomotives using coal, with the view of more effectually producing the perfect combustion of the coal gas.

*Thirdly:* Provision will be made for the admission of the requisite large volume of air to effect that combustion.

*Fourthly:* The use of short tubes in place of the long tubes hitherto employed.

Hereafter, then, the evaporative power of a boiler will be calculated, not by the number of square feet of *tube surface*, but by the area of the available portion of the *face-plates.*

With reference to the heating power of the first twelve inches, lineal, of the tubes, already spoken of, this being so near a constant quantity, need not be taken into consideration when calculating the varying areas that may be required for any boiler.

Independently, then, of this quantity, the steam-generating power may be estimated as equivalent to the gross area of all the face-plates, minus the area occupied by the orifices of the tubes, whatever may be their then number or diameters.

Without reference to the tubes, it appears by practice, that one square foot of the available area of the *face-plate* is required for each square foot of *grate-bar-surface*, and this may safely be taken as the basis of a law of proportions for future calculation. Thus, for a furnace of twelve square feet, the heat-transmitting area may be found in a single face-plate of the same extent.

But, take the case of a large steamer like the *Warrior*. Here each furnace, say of 6 feet by 3 feet will have 18 square feet of bar-surface. The gross area of the face-plate of each stack of tubes may also be taken as equal to 12 square feet—one-fourth of which being occupied by the open ends of the one hundred tubes, there will remain but 9 square feet of heat-transmitting surface, against 18 square feet of grate surface—just one half of the required area for evaporation. In such case a *second*, or even *third face-plate* will absolutely be required for the transmission of the heat from so large a grate. If this quantity be not supplied, one half the generated heat must, of necessity, pass away as *waste* by the chimney. Estimating the evaporative value of a second face-plate at two-thirds that of the first, and of a third at one-third that of the first.

It is the presence of this large quantity of heat in the chimney stack that has set the ingenuity of engineers at work in considering how it might be utilized. Among the modes of effecting this object, the process for heating the feed water, and also the *super-heating* process was invented. Nor can we be surprised at the high temperature of the escaping unappropriated products, seeing how little really heat-transmitting surface has been provided.

We now see how this supposed case of the *Warrior's* proportions are confirmed by the experiments here detailed. Take, for instance, experiment No. 3. In that case, the gross area of the first face-plate was 20 by 20 inches, equal to 2·75 feet. From this deduct the area of the 25 tubes, and there remains the true heat-transmitting surface of but 2 square feet, to take up the heat generated in a furnace of 3·75 feet, little more than half the required surface. We see, then, the absolute necessity for the additional two face-plates, as shewn in the Fig. 3, and their practical value in appropriating the 425° of waste heat, and evaporating the additional 470 lbs. of water; and, further, the increasing the evaporative value of each pound of coal from 4·69 to 6·22.

Here we have sufficient grounds for taking, as a general law, the providing one foot of effective face-plate surface for every one foot of grate surface.

Here is no speculative theory, but a practical application of the heat of the escaping products, truly called *waste heat*, to the legitimate purpose of increasing the amount of steam generated.

How far this law may hereafter be modified, will be the result of future practice.

We shall not err, however, in determining the required amount of heat-absorbing and transmitting surface, not as hitherto by the gross amount of *tube surface*, but by the area of the effective heat-intercepting portion of each *face-plate*.

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## IV.—ON THE APPLICATION OF THE STEAM JET IN AID OF THE DRAUGHT.

After examining the value of the face-plate surfaces, we have next to consider how these surfaces may be brought more actively into operation. This may be done by aritficial means, and, although hitherto ignored by engineers, will nevertheless be found not only easy in practice but efficient in result. The evaporative power of boilers may, then, be improved—*First*, by an appropriation of a larger measure of the heat from the products of combustion, with a larger amount of face-plate surface, and a consequent reduction of the temperature of the waste heat in the chimney; and—*Secondly*, by an increase of the draught which accelerates that appropriation.

The necessity for this connection has been satisfactorily proved by experiment, shewing that, provided adequate provision has been made for the appropriation of the heat, the quantity of steam generated will be increased in the ratio of the draught. Here we recognize the importance of increasing either the number of face-plates, or their available areas. The exact portion of such face-plate practically available for intercepting the gaseous current from the furnace will, of course, be determined by the amount of space or clearance between the tubes. The most beneficial extent to which this clearance may be carried must be decided by practice hereafter. It may, however, be said that tubes of 3 to 4 inches internal diameter, with a clearance of 1 to 2 inches, have given favourable results.

The artificially increase of the draught may be made in the following ways:—*First*, by a series of *steam jets* in the *ash pit*—the current of air induced by the action of the jets below the bars, and through the fuel, producing an increased combustion. *Secondly*,

by a similar series of steam jets in the *chimney*. *Thirdly*, by the use of the fan, outside the chimney, in the manner adopted by Peclet.*

His conclusion was that the rotary fan, with plain wings, but with eccentric motion, was to be preferred.

In this case, he has shewn that "a ventilator which employed the power of six "horses, produced a draught equal to that of fifty horses obtained by means of the "natural draught." Impressed with the importance of the subject, I made experiments with a fan worked by an engine of one-horse power, the results of which were as follows:—

| Experiments. | Coal used per Hour. | Water evaporated per Hour. | Water evaporated per pound of Coal. | Pyrometer heat in Flues. | Temperature of waste heat in Chimney. |
|---|---|---|---|---|---|
| | lbs. | lbs. | lbs. | Degrees. | Degrees. |
| 1. With fan draft. | 265 | 2,454 | 9·26 | 1,025 | 650 |
| 2. With ordinary chimney draft. | 215 | 1,552 | 7·21 | 725 | 410 |

The evaporative power of the boiler was thus increased by the fan from 1,552 to 2,454 lbs. of water, within the hour, and from 7.21 to 9·26 lbs. evaporated *per pound of fuel.*

It is here of primary importance that we clearly understand the right mode of applying the steam jet, as it has often been seriously misapplied from the want of knowledge of the principle on which it acts. In illustration of this may be mentioned a serious mistake committed in one of the Dublin steamers. In that case a series of jets were introduced in the chimney, in supposed aid of the draught. In the centre of the chimney was a 2½ inch tube, in a circle of two feet diameter. In this were drilled sixty orifices, 1 inch apart, each of ¼ inch diameter. Through these orifices sixty streams of steam issued continuously, with a force equal to the pressure of 20 lbs. per inch. Under the conviction that the areas of the jet orifices were too large, and that they were so near each other as to neutralize their respective action and effect, I had an apparatus made of the same dimensions in a tube representing the chimney. To this the air meter was attached so that the quantity of air, brought in aid of the draught, could be ascertained. In the first experiment the sixty ¼-inch orifices—the pressure of the steam being but 7 lbs.—were all open. The revolutions of the meter were 540 per minute, shewing that 540 cubic feet of air were artificially brought in, and representing the amount of induced current produced by the sixty steam jets. In the next experiment each alternate steam jet was plugged up, thus reducing the numbers in action from

* See C. W. Williams's *Treatise on Combustion:* Weale's Rudimentary Edition.

sixty to thirty, increasing their distances apart from 1 to 2 inches with a saving of *one-half* the expenditure of steam. The result was, an increase in the number of revolutions of the meter (or cubic feet of air, per minute), from 540 to 635, as noted in the table, being a gain of seventeen per cent. In the third experiment, a further reduction in the number of orifices and jets was made, their distances apart being then *three inches.* The result was a still further increase of revolutions and cubic feet of air passing, from 625 to 745, being a further gain in aid of the draught of nineteen per cent. more of air introduced with a commensurate saving of steam. It is needless to dwell on the value of this source of economy.

The next series of experiments, as shewn in the Table, consisted in the reduction of the areas, or size of the several orifices and jets of steam, from *one-fourth* to *one-eighth*, and then to *one-tenth* of an inch. In each case the results were as remarkable as beneficial.

We there see that thirty jets of even one-tenth of an inch, sectional area, when placed at *three* inches apart, were more effective than sixty jets of a quarter of an inch when placed within but one inch of each other. As regards the economy of steam, the inspection of the last column in the Table, giving the gross area for the exit of the steam in each experiment, is sufficiently expressive.

This result shewed that the efficiency depended, not on the quantity of steam issuing, but on the strength of the jet and the amount of induced current which it produced.

| Revolutions of Meter per minute. | | Pressure of Steam on Boiler. | No. of Jets. | Size of Jets. | Gross area of Jets in inches. |
|---|---|---|---|---|---|
| $\frac{1}{4}$-inch Jets | 540 | 7 lbs. | 60 | $\frac{1}{4}$ inch | 2,945 |
| | 625 | " | 30 | " | 1,472 |
| | 745 | " | 20 | " | ·981 |
| | 725 | " | 15 | " | ·736 |
| | 700 | " | 12 | " | ·589 |
| $\frac{1}{8}$-inch Jets | 740 | " | 60 | $\frac{1}{8}$ inch | ·736 |
| | 615 | " | 30 | " | ·368 |
| $\frac{1}{10}$-inch Jets | 700 | " | 60 | $\frac{1}{10}$ inch | ·600 |
| | 600 | " | 30 | " | ·300 |

This needs no comment. Here we have practical results arising from a just appreciation of the principle on which the efficiency of the jet depends, in opposition to the mere random and even mischievous application of a most useful power in aid of the natural draught in chimneys. It is only necessary to add, that the plan adopted

by the makers of the boiler referred to in the use of these chimney jets and at a considerable expense, was altogether inoperative for good, and had to be removed. The waste of steam was not only very great, but was productive of much inconvenience, as, by mixing with the smoke in the chimney, large masses of blacks fell on the decks, and to the great annoyance of the passengers. By this examination we are enabled to appreciate not only what was *erroneous*, but what was *beneficial*, in the use of the steam jets, namely—that they should be at such distance apart as to allow each to have its full effect in producing the induced current. Adopting these results, practically the most beneficial size of the jets, both in the ash-pit and chimney, were confined to $\frac{1}{8}$th orifices, with intervening spaces of at least 4 inches.*

We must be careful, however, that we do not overestimate the value of the *fan* system, lest we be led to suppose that, *of itself*, it would supply the required amount of appropriation or utilization of the heat. Where there is a deficiency in the *effective* (not *nominal*), amount of heat-transmitting surface, the action of the jet and its increased draught may even be injurious, since, although it may produce some increase in the quantity of steam generated, it will also cause a much larger amount of fuel to be uselessly consumed, and increase the temperature of the escaping waste heat by the chimney. Unless, then, an adequate improvement be made in the mode of appropriating the heat beyond that at present employed, little will be gained by any increase in the draught as shewn to take place when the firebox area of the locomotives was enlarged.

In the locomotive, where the draught is at its maximum, the quantity of heat lost and the temperature of the chimney are enormously out of proportion to the quantity usefully appropriated in the generation of steam, the draught being so much in excess of the means of appropriating the heat generated.

Where the size of the furnace and the quantity of fuel consumed is moderate, and only in due proportion to the wants of the engine, the evaporating power of the ordinary face-plate may be sufficient. Where, however, as is almost universally the case at present in marine boilers (the furnaces often extending to 7 or 8 feet in length), the quantity of fuel used and heat generated is greatly in excess of what can be utilized.

In such case, both the additional areas of face-plate and of extra draught are essential to economy and efficiency.

* For illustrations of these results, see C. W. Williams's *Treatise on Heat in its Relations to Water and Steam:* Second Edition, Longman.

## V.—ON THE USE OF COAL IN LOCOMOTIVES AND MARINE BOILERS.

Having considered the questions of the *generation* and application of the heat, and the effect of an increase of draught by the aid of steam jets, I now come to the use of coal in locomotives and marine boilers, and the prevailing practical differences between them.

In the discussion on Mr. Clark's Paper, Mr. S. Lloyd remarked that "the improve- " ments effected since 1851 were not very striking, except on the important change from " coke to coal, in which respect certainly a very great improvement had been made, " causing a large saving in the consumption of fuel." He asked "What were the " comparative results of different engines in economy of fuel?" Mr. Clark replied that " the comparative value of the firebox and of the tubes, as heating surface, first required " particular attention." Of this, indeed, there can now be no doubt. He thought "the " two London and North-Western engines furnished valuable information on the point. " The performance of the inside cylinder engines, with 242 square feet of heating surface " in the firebox, was not so good in work done, per lb. of coal, as with the engine with " only *one-third* the extent of heating surface in the firebox, but *rather more* in the tubes."

Here, while he commits himself to the advocacy of the tube surface, he fails in not perceiving that this enlargement of the area of the firebox surface to 242 square feet does not in the least *enlarge the area* of the *face-plate*, the true *means of heat* transmission, and, therefore, had no increase in the evaporating power in the boiler.

From this it is evident that the heat generated in the larger firebox was not sufficiently appropriated in the generation of steam, and there could be no use in consuming more fuel and generating more *heat*, if that heat were not utilized.

The distinction, as Mr. Clark observed, between the "firebox for burning coal and " slack should not be overlooked. For *coal*, 13 to 15 square feet of grate is sufficient; " but for *slack*, the inside cylinder engine has 26 square feet of grate. The difference " of fuel leads to a difference of treatment, inasmuch as *special provision* is made for the " admission of air *above the fuel* for consuming coal in pieces, in *addition* to the air that " passes *through the grate*."

Here we have it for the first time in print, on any engineering authority, that air should be admitted *above the fuel*.

Here, then, is practice prevailing over theory, by adopting a "*special provision*" for the admission of air.

Why, then, the owners of marine steam-ships ask, is it that the makers of marine boilers do not adopt the same practice? The reverse, however, is the fact. No such "special provision" is made, although there is manifestly a greater necessity for it, seeing that the quantity of coal used in each furnace is so much greater, and consequently so much more gas momentarily generated, requiring so much more air for its combustion, above the fuel, where alone it exists. Do the makers of marine boilers assert that those who design locomotives are wrong, or do they deny the practical result? Mr. Murray, and others of no mean authority, deny the necessity for such special provision, or the admission of air above the fuel, and engineers in general conform to such erroneous theory.

I speak feelingly on this subject, seeing that the Dublin Steam Company suffer seriously in a financial point of view, in the absence of any provision for the admission of the enormous volume of air required for the combustion of the gas generated in the forty furnaces of each vessel, by the emission of dense smoke from the chimneys, and the consequent waste of fuel in the necessary forcing the fires, which is absolutely required to keep up the due pressure of steam.

To this may be added the fact that, by the mischievous practice of having the boilers in ranges on each side of the ship, with a stoke-room most inconveniently placed between the two lines of furnaces, they are necessarily so short as to render any subsequent effort to improve them impossible.

The absence of such special provision prevails in the boilers even now constructing both for the navy and mercantile steamers. This discrepancy in the practice as regards locomotive and marine boiler makers is sufficient evidence of the absence of principle or system, and demands enquiry.

Had Mr. Clark looked into the chemical question, as regards the combustion of the gas from coal in furnaces (and which he had before him in my Treatise, and taken from the highest chemical authorities), he would have avoided the mistake in speaking of the admission of air *through the grate*.

In truth, no pure air does, or could pass up through the mass of incandescent fuel on the grate. What passes is *combustible carbonic oxide*, formed *from the carbonic acid* generated on the combustion of the coke of the coal—which I have rightly called coke-gas; but, as even this requires one half the volume of air that the coke of the coal did, the

admission of air above the fuel is still necessary for its combustion,* the failure of which is one of the greatest sources of waste in the locomotive.

It may here, however, be added, that even were this carbonic *oxide* supplied with air, and its combustion completed, it could produce no useful effect, seeing that its heat could not be utilized in the absence of sufficient face-plate area.

If we only look into the firebox of a locomotive at any station, we cannot mistake the existence of this carbonic oxide, or coke-gas. It has a semi-transparent flame of a bluish tint, but, as it gives out no *black* smoke, it is erroneously supposed that combustion is complete; yet, the great heat which its combustion would have generated is necessarily lost.

It is strange that the existence of this peculiar gas in the firebox of locomotives should not have been noticed.

As a law which cannot be dispensed with, there should always be a special provision and space as a combustion chamber, in which the air admitted, whether through a perforated doorway or behind the furnaces, can be mixed with the gases and then combustion completed. This chamber should have at least one foot lineal, between the bridge and the first face-plate, for every lineal foot of grate. This distance or run is quite compatible with a boiler of 12 feet long; a shorter boiler being wholly incompatible with the process of combustion. Nevertheless we find boilers of but 8 feet in length being introduced, even in war vessels. Of the inside cylinder engines of the London and North-Western lines, Mr. Clark further observes:—" The boiler has been designed for burning coal with " a *combustion chamber*, and a double compartment of firebox for *alternate firing*."

Here we have proof of the superior attention, practically, to the subject, and the advance made by the designers of locomotives in the use of coal. This double compartment in the furnace has a chemical value of great importance which Mr. Clark has omitted to notice, namely, that the gas generated from the coal on the *fresh-charged* side is kept at a high temperature by the reflected heat from the then incandescent fuel on the opposite uncharged side, a matter of considerable importance, not only in preventing the cooling effect which takes place in the ordinary mode of heavily charging, but sustains that temperature in the gas which is essential to its ignition and combustion. Now, alternate side-firing, though without the double compartment, comes

* " Carbonic oxide may be obtained by transmitting carbonic acid over red-hot fragments of charcoal contained in an " iron or porcelain tube. It is easily kindled; combines with half its volume of oxygen, forming carbonic acid, which retains " the original volume of the carbonic oxide.

" The combustion is often witnessed in a coke or charcoal fire. The carbonic acid produced in the lower part of the fire " is converted into carbonic oxide as it passes up through the red-hot embers."—*Graham's Elements of Chemistry.*

to the same thing. Its value was shewn at the Newcastle trials, where it was adopted by Sir W. Armstrong with excellent effect, and comes in favourable contrast with the ordinary but vicious system of fully charging the furnace almost up to the doors, and so high that it reaches the crown plates, thus filling the very space that should be allowed for the air to mingle with the gases preparatory to combustion.

The very erroneous system, also, of making the furnaces so shallow favours the objectionable system of charging.

In marine boilers there should always be a space of 12 inches, at least, clear between the fuel and the crown plates. The mode of firing alternately the two sides of the furnace, however, should be insisted on, attended as it is with this additional advantage, that the stoker can see clearly to the far end of the furnace, and keep it charged, a matter much neglected in practice.

In the use of coal, then, the constructors of locomotives are far in advance of those who design marine boilers, as having a *lengthened space* of many feet, lineal, between the firebox and the tube-plate, rightly called the combustion chamber. In marine boilers, however, it is directly the reverse, as seen in the *Great Eastern*, the *Warrior*, and many other vessels; so also in the Dublin mail packets, where, although there are forty furnaces, not a single foot of such combustion chamber exists.

When those vessels were constructing, the engineer was asked where the large volume of gas (10,000 cubic feet from each ton of coals) was to be consumed, or the 100,000 cubic feet of air for that purpose, to be introduced? The only answer was, that "*there should be no smoke.*" Nevertheless, as predicted, those vessels were most inveterate in continuously pouring forth their dense volumes, as well as being most expensive in the consumption of fuel.

Here it may legitimately be asked, why should the owners of steam-vessels be the sufferers, not only by the nuisance, but in the cost incurred by these mistakes?